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Height-Age and Site Index Curves for Pacific Silver Fir in the Pacific Northwest

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Abstract

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Forty felled dominant and codominant Pacific silver fir trees (*Abies amabilis* Dougl. ex Forbes) from 39 locations provided the basis for height-age and site index curves. Trees were from upper slope forests of the Cascade Range in Oregon and Washington. Trees ranged in age from 100 to 300 years and were identified by their height-growth trend as free growing throughout their lives. Twenty additional dominant trees with height growth retarded when they were young were excluded from the site index and height-growth analyses. The early rate of diameter growth of these 20 trees was used to develop a general guideline identifying nonfree-growing dominant trees. Equations and height-age curves are presented. A multiple regression equation was developed to express site index (height at age 100) as a function of total tree height and age at breast height.

Equations were developed to estimate the number of years free-growing trees need to reach breast height for the range of site index values. Conversion equations are provided to estimate height at age 50 for curves representing index heights at age 100. The results give forest managers working tools for use in managing silver fir.

Keywords: Site index, Pacific silver fir, *Abies amabilis*, height growth, dominant, stem analysis, Pacific Northwest.

Summary

Dominant and codominant silver fir trees felled beginning in 1965 as part of a study of upper slope conifers of the Cascade Range in Oregon and Washington had both free-growing and nonfree-growing growth trends. Height and age of each tree were carefully graphed, and the nonfree-growing trees were recognized and separated. Analysis was intended to represent trees that had been free-growing throughout life. A few more felled trees were added to the data in 1986.

About half of the free-growing trees were in sets of two or three identified to a specific plot area; these sets represented a specific single site index. The remainder were single tree samples. Plotted height-age curves of the former indicated important differences among trees on a plot. These differences suggested that the trees would be better used as combined samples representing given average site indexes rather than as individual trees each with its own site index. The latter procedure has been commonly used to develop growth curves but seemed unwise for this study because it ignores the real variation among trees on a plot. The existence of half of the tree data in the form of plots allowed investigation of this point.

Graphically smoothed trends of trees averaged by plot were used for constructing standard height-age curves. Single trees were compared graphically with the standard curves and then were combined in groups of two or three according to similarity of curve shape and height at site index age 100 years. Grouped in this manner, they had the same tree-by-tree variation as trees that had grown together on sample plots.

Each set of two or three trees was mathematically fitted with a smoothed height-age curve. These values were then used as one of three alternatives for comparing data points to curve trends.

- Alternative A—Individual data points were compared to smoothed height-age trends by using mean site index per plot and a separate equation per plot.

- Alternative B—Individual data points were compared to results of a single-equation system fitted by using each tree with its individual estimate of site index.

- Alternative C—Individual data points were compared to results of a single-equation system fitted by using trees grouped by and with an estimate of mean site index.

Alternatives B and C were each fitted to the following equation form (FORTRAN notation used, text equation number 4):

$$\text{Height} - 4.5 = (\text{Site index} - 4.5) * \{1 - \text{EXP}[-(c + d * (\text{Site index} - 4.5)) * \text{Age}]\} ** f / \{1 - \text{EXP}[-(c + d * (\text{Site index} - 4.5)) * 100]\} ** f$$

Alternatives B and C showed little difference in value of coefficients. Plotted differences (of height estimate minus actual data) were similar for all three alternatives. Alternative C, with slightly less variance in ages less than 100, was selected as the basis for a system of height-age curves.

A multiple regression equation was fitted with site index as a function of age and total tree height for individual trees, each with an individual estimate of site index. Fitting in this manner followed the method that would be applied in using the equation. Some additional estimating precision was gained by adding other variables defined by measurements of height at 5 and 10 years above breast height.

Silver fir grows with some other tree species that have site index referenced to age 50 rather than age 100. A convenient conversion equation was developed that relates site index of silver fir at age 100 to the height each such site would reach at age 50.

An estimate was made of the time required for the free-growing felled trees to reach breast height.

A special study of a limited number of the felled trees for which we had diameter-increment records led to a guideline for defining dominant trees having retarded height growth in earlier years: Any dominant tree whose radius at 20 years from the pith is less than 0.9 of an inch should not be used as a sample tree for site index.

Contents

Introduction

Forest managers in the Pacific Northwest are showing an increasing interest in the upper slope forests of the Cascade Range in Oregon and Washington. Pacific silver fir (*Abies amabilis* Dougl. ex Forbes) is a major tree species in these forests, forming both pure stands and mixes with other conifers.

Managers need an accurate assessment of stand productivity to help them make sound decisions about these forests. Height-age growth curves and companion site index curves help in estimating relative productivity. Height-growth curves are essential for making accurate forecasts of future stand productivity.

This paper describes the development of height-age and site index curves for silver fir based on felled and sectioned trees. Beginning in 1965, forest scientists from the Pacific Northwest Research Station began a systematic collection of tree data from the upper slope forests of the Cascade Range. Locations ranged from McKenzie Pass, Oregon, to Stevens Pass, Washington. Results of that work are reported by Curtis and others (1974) for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and by DeMars and others (1970) and Herman and others (1978) for noble fir (*Abies procera* Rehd.). Even though noble fir and Douglas-fir received the main emphasis, a limited number of silver fir trees were also selected, felled, and measured. These trees formed the basis for this study.

Materials and Methods

The Felled-Tree Database

The methods of field measurement are described in detail by Herman and others (1975). One or more dominant or codominant silver fir trees were felled in each stand and cut into logs. Annual growth rings were counted at each log section and later verified on samples carried to the laboratory.

The log cross-sectional points examined on the tree boles were at stump height, at 4.5 feet (breast height), at about 9 feet, and then at 8- or 16-foot intervals to the tip of the tree. Measurements were made at shorter intervals where damage or past bole breaks were suspected. (During analysis, all measurements were adjusted to conform with the assumption that cross-sectional points were made at the middle of the annual growth span [Dyer and Bailey 1987].)

On a few selected trees, ring growth at breast height was permanently recorded from one selected radius by scribing the distance between rings at 10-year intervals on transparent Mylar[1] sheets.

A few trees were felled in 1986 and added to the older data. In all, 69 trees from 39 locations were available; 40 free-growing trees were used in the main analysis.

A limited separate study was made in 1986 on free-growing trees in reproduction age classes. The purpose was to estimate the years required from seedling germination to 4.5 feet for free-growing trees of largest diameter.

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[1] Use of a trade name does not imply endorsement or approval of any product by the USDA Forest Service to the exclusion of others that may be suitable.

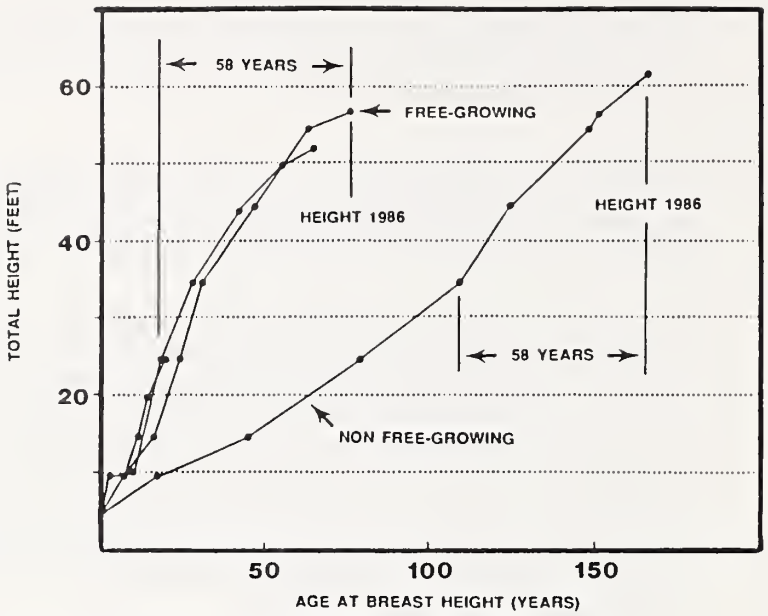

Figure 1—Height growth of free-growing and nonfree-growing dominant silver fir trees on the Racehorse plot.

Preparing the Data

The height and age of each felled tree were carefully plotted on cross-sectioned paper, and lines were drawn to connect the points. From these graphs, the heights at age 5, 50, and 100 years were determined for each tree for later use in analyses.

The ring counts at stump height allowed estimation of age below breast height but did not permit precise counts of total age because stump height varied and few were at ground level. All heights above breast height were referenced to age at breast height, and the subequent analysis was based on age at breast height.

Free-Growing Trees Defined

The plotted height-age trends clearly showed that some trees had reached their dominant position—at time of cutting—after suppression in early years. Growth curves for such trees were different from those of free-growing trees. Examples of both are given in figure 1, which illustrates the serious impact trees with suppressed early growth could have if allowed to influence the shape of height-growth curves presumed to represent the free-growing component of a stand. All nonfree-growing trees were excluded from the height-age, site index analysis.

An estimate was desired of the years required for free-growing trees to reach breast height. On the plotted graph of each such tree, the trends above breast height were extended (as if they had been free-growing from germination) through breast height to total age zero by using available measurements near the stump. Some subjective fitting was required for some trees. The number of years required to reach breast height was read from the graph of each tree. Tree data were later analyzed both by individual trees and as averages.

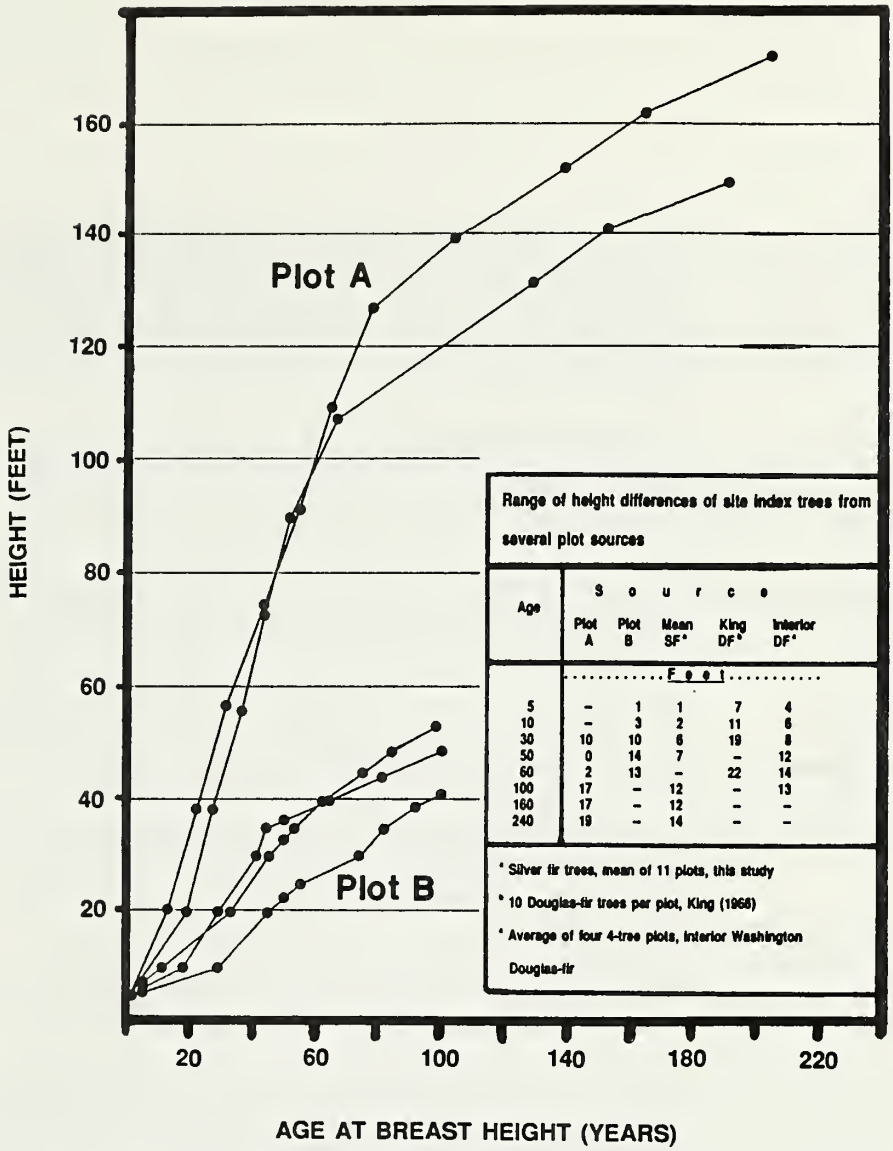

Figure 2—The range of height differences that can occur among free-growing trees on a plot.

Average Free-Growing Height-Age Curves

Height of trees on plots with two or more free-growing trees (group 1, summarized below) was plotted as a single average curve representing all trees on each plot. Typical variation of tree height growth is illustrated in figure 2. Note the range of height differences that can occur on silver fir plots. Other data included on figure 2 list:

- The mean difference in height for 11 silver fir plots with two or more free-growing tree growth-segments.
- Range of height for trees on a plot given by King (1966) in his analysis of the height growth of coastal Douglas-fir.
- The average range of height differences on four plots, each with four interior Douglas-fir trees, for which data had been collected for another study. The average plotted height-age curves of the trees on these four plots conformed closely to the shape and range of the curves for free-growing silver fir found in this study.

The average curve from each plot was then transferred to a single page of graph paper. This produced a sheaf of polymorphic height-age curves representing the most stable portion of the felled-tree data. None of the 10 curves crossed each other above age 50, but several were closely parallel. Some crossing of curves occurred as they merged to height 4.5 feet at age 0, but in general the growth trends were surprisingly orderly.

The sheaf of curves ranged from 46 to 115 feet in height at age 100 years. Nine of them reached age 100 or greater. Four of the nine reached age 160 and three reached age 240.

The average height difference among free-growing dominant trees within plots for ages 50, 100, 160 and 240 years were, respectively, 7, 14, 12, and 14 feet, or an average of 12 feet.

Constructing a Sheaf of Standard Free-Growing Curves

From the sheaf of plotted average curve trends, a second sheaf, referred to as standard curves, was constructed at intervals of 12 feet of height at age 100, beginning at height 50. (This was a graphic derivation of height-age curves.)

The standard sheaf of curves was used for comparing the curve shape of all other trees by overlaying the graphs on a back-lighted surface. Curves of conforming trees followed the standard curves. Curves of nonconforming trees crossed one or more of the standard curves.

Four Groups of Data Defined

The procedure for visually comparing individual trees to standard curves led to the following useful classification of all trees in the database.

Group 1—Multiple, free-growing trees on plots, each representing a specific site index; 24 trees, 10 plots, the basis for the standard height-age curves. Plots had two or more trees whose average curve reached or exceeded a height of 20 feet by age 40 and a height of 14 feet or more by age 20.

Group 2—Free-growing single trees; 25 trees, later combined and treated as 11 plots, each representing a specific site index. The trees had the same height-age specifications as group 1.

Group 3—Plot averages or single trees with minor early height-growth restriction; six trees, five plots. Height-age curves reached or exceeded 20 feet by age 40 but were less than 14 feet at age 20.

Group 4—Plot averages or single trees with obvious early height-growth restriction; 14 trees, 9 plots. Height-age curves failed to reach 20 feet in 40 years. After age 40, a tree sometimes enters a period of rapid height growth; for some of these trees, field notations indicated a central core of suppressed diameter growth rings. There was no way to determine from the data if suppression was of the conventional sort or if the influence of heavy snowpack was involved.

Four plots with eight trees failed to conform to any of the above categories. One, a plot with felled trees collected in 1986, was from a locally recognized atypical stand. The cause for its nonconforming curve shape is not known. The unusual shape of two other single trees presumedly was caused by unrecognized height losses in early years. Trees from these three plots were excluded from further analyses.

The fourth plot—known as the Granite Mountain plot—had three trees and a very low site index. It was measured in 1986, and the trees were known to be free growing. This plot was the only exception to the definition that free-growing trees should exceed 14 feet of height by age 20. These trees were included in group 1.

Analytical Approach

Consider what has been accomplished so far. The graphic analysis of multiple free-growing individual trees in different stands has defined the scope and sensitivity range of the population of significantly different height-age curves for silver fir in the geographic subregion sampled.

- Ten separate site index levels were defined beginning at height 50 feet at age 100 and extending through height 160. Extension beyond the limits of the data to height 180 is desirable. Thus, the total population needed to define the height-age relation for silver fir is probably 12 height-age curves.

- A measured range of 12 feet defined the real difference between levels of height-growth site index curves when the within-plot variation of individual trees was considered.

The standard curves were, in effect, a systematic series of boundaries defining the range within which free-growing dominant trees occurred. Any two or more trees conforming to the shape of the standard curves, and whose height-age curve fell within a particular pair of standard curve lines for ages 50 to 250, represented the shape of that part of the standard curves defined by a particular site index. (Below age 50, trends might exceed the boundaries of the standard curves). The height and age of any two or more such trees could be combined for a single estimate of curve shape (as was done for the several individual tree measurements on a defined plot). This was literally true for trees whose average values fell midway between the standard curves. It held true in principle for a group of trees whose average trend fell along rather than precisely between two standard curves.

Combining several individual trees for an average site index has a statistical advantage over individual trees used alone. Most site index equation systems include a term forcing the fitted equation through height at index age. Residuals plotted for such trees are, by definition, pinched to a zero value at index age thereby producing a pattern of residuals contrary to the usual assumption of homogeneous variance. If an average site index of several trees is used, an estimate of real variance is included in the process, and a more homogeneous pattern of residuals results.

Choice of approach also depended on anticipated application of results. Our twofold intent considered single-tree versus average-tree applications as follows:

- To develop equations estimating mean height growth of specific levels of site index for silver fir as represented by several free-growing trees.

- To develop equations estimating site index (tree height at age 100) from individual sample trees with known heights at any age. We hoped to use additional height measurements near breast height to increase the precision of site index at ages 50 and younger beyond the level usually possible with routine site index variables.

Average plot heights versus individual tree heights—The height-age curves representing overall regional trends logically should be estimated by using average height-age trends and an average site index for each plot or group of trees representing the same site index, rather than by using the height and age of individual sample trees in a stand, each with its own estimate of site index.

Estimates of site index should be made from measurements of individual tree heights and age—not plot averages—in a stand.

Thus, using a single tree to represent the height growth of a plot or stand ignores the range of real variation of height growth within the plot. This leads to two undesirable results:

- The overall curve shape of the single tree may not represent the average shape appropriate for the site index of the plot or stand.

- A site index number (height at a given index age) assigned to the single tree may misrepresent the mean site index of the plot or stand.

An argument against fitting the data according to the logic given above is that about half of the free-growing trees in the data base were single trees not associated on field plots. Even though those trees can be grouped according to similarity of curve shape and site index (both of which varied within the same limits as trees growing together on field plots), some may regard such grouping as statistically unsound.

The approaches used—Based on the foregoing reasoning, the following analytical alternatives were selected for fitting height-growth and site index relations.

- Individual tree height, age, and site index were used as the basic data to fit an equation for estimating site index.

- Three slightly different approaches were used to fit equations estimating average height-age curves. These are referred to as alternatives A, B, and C.

Alternative A—Use separate smoothed average height-age curve for each defined site index group (plot). This procedure—used by King (1966)—stabilized the average curve shapes by eliminating the high within-plot variation. A similar result, of course, was accomplished graphically, above, by developing the standard sheaf of curves. Differences between these smoothed estimates of height and the measured values were used later as a base estimate of data variation, independent of any influence from fitted equation systems simultaneously applied to all sites.

A disadvantage of this approach is that an equation and its attendant curve shape has to be selected for fitting each plot. An arbitrary selection of curve shape could influence the fitting of the overall curve system for the combined plot analysis.

Alternative B—Use individual tree data and individual site index estimates for each tree. This is the equivalent of using single trees, with neither mean site index nor plot identification, as the basis for a system of height-age curves.

Alternative C—Use the individual tree measurements on a plot, without any attempt at smoothing, as the basis for a system of height-age curves; assign the mean plot site index height to each tree.

Combining Single Trees for Average Site Index Groups

The 25 trees in group 2 were free-growing trees. These single trees were classified by similar height trends and site index and were treated as 11 plots each having two or more trees. The maximum difference in height between trees ranged from 7 to 22 feet and averaged 14 feet. This was slightly larger than the average height difference (12 feet) observed on the plots in group 1.

The height trends of the trees on each of these 11 redefined plots were averaged by ages; the resulting curve was plotted and compared with the standard sheaf of curves. General shape of each average curve conformed closely with one of the standard trends.

Trends from the 11 plots included ages up to 300 years. With these as added support, the sheaf of standard curves was considered valid up to age 300, an increase from age 240—the limit of data for the trees used to make the standard curves. Graphic extrapolations of the curves suggested possible asymptotic levels reached by each standard curve between ages 400 and 700 years.

The 11 plots from group 2, together with 10 plots from group 1, were used as 21 samples representing the shape of the 12 site index levels describing the range of height-growth curves for the region. These 21 average trends, each with an average site index, were the basis for mathematical derivation of equations to describe the free-growing height-growth curves for the region.

Height Trends of Nonfree-Growing Trees

Visual comparison of the standard curves with the curves for trees in group 3 (those with minor early growth restrictions) and group 4 (trees with obvious and sometimes extended periods of early growth restriction) led to the same conclusion. By sliding the image of the tree curve toward zero along the age scale (abscissa) of the standard curve, the oldest portion of the tree curve without exception (for the 17 subject trees) closely matched one of the standard curves; that is, released trees that became dominants were at later ages able to follow the height-growth trend of trees dominant all their lives.

This finding confirmed, in silver fir, behavior similar to what Assmann (1970, p. 46) describes for both European silver fir (*Abies alba* Mill.) and Norway spruce (*Picea abies* (L.) Karst.).

Meyer (1937, p. 5) uses the same principle when defining "effective age" of dominant western hemlock trees (*Tsuga heterophylla* (Raf.) Sarg.) that have suppressed rings at the core, followed by released outer rings. He projects the growth rate of the released rings back to the center of the tree to estimate the number of years it would have taken the tree to reach the released point if it had been free-growing all its life. Meyer's adjustment has the same effect as our sliding the plotted trends along the abscissa of the standard curves.

In summary, the visual evaluation of the felled tree data showed that:

- Averaging tree heights over ages by plot led to consistent, stable height-growth curves; that is, standard growth curves, for free-growing trees (group 1).
- The average height growth for the pooled free-growing single trees (group 2) conformed to the shape of the standard growth curves derived from group 1.
- The upper portion of dominant trees that had earlier been nonfree-growing (groups 3 and 4) conformed to the growth of free-growing trees. The height trends of the lower portion of the same trees differed from the trends of free-growing trees.

These findings led to selection of groups 1 and 2 for computer fitting of average growth curves by plot and for combining the average trends into a single system of site index and growth curves.

Developing Smoothed Heights by Plot (Alternative A)

For fitting purposes, smoothed heights were desired for each age given for a data point for each tree. A fitted equation was needed rather than graphically fitting a smoothed curve to the trees in each site index group (plot).

Two equations seemed appropriate. Equation (1) is a form similar to one described by Richards (1959). It is also derived in a more basic form by Prodan (1968, p. 370). Equation (2) is also discussed by Prodan (1968) and is used by King (1966) for Douglas-fir height curves. These equations are given in FORTRAN notation, that is, * = times and ** = raised to the power of:

$$\text{Height} - 4.5 = (a + b * S) * \{1.0 - \text{EXP}[-(c * \text{Age})]\} ** f \text{ , and} \quad (1)$$

$$(\text{Age} ** 2) / (\text{Height} - 4.5) = a + b * \text{Age} + c * (\text{Age} ** 2) \text{ ,} \quad (2)$$

where

EXP = is the base of natural logarithms,
Height = total tree height in feet,
S = (height at age 100) – 4.5 feet,
Age = age at breast height, and
a, b, c, and f are regression coefficients to be estimated.

Equations (1) and (2) were fitted to each plot, and the resulting smoothed height-age trends were compared with the original mean plotted values.

Equation (2) had consistently smaller deviations from the plotted data so was judged as being more appropriate for the purpose intended than was equation (1). Consequently, equation (2) was fitted to each site index group (plot) to create smoothed heights for each age data point. This set of smoothed values is referred to as alternative A during later comparisons.

Fitting a System of Height-Age Curves

Equation (2) was difficult to condition through index age. The following three modified forms of equation (1) therefore were examined as the basis for estimating a system of height-growth trends. All curves were fitted by using procedures in program NLIN described by the SAS Institute, Inc. (1985).

$$\begin{aligned}\text{Height} - 4.5 = {} & S + (a + b * S) * \\ & \{1.0 - \text{EXP}[-(c + d * S) * \text{Age}]\} ** f \\ & - (a + b * S) * \\ & \{1.0 - \text{EXP}[-(c + d * S) * 100]\} ** f \text{ ,}\end{aligned} \quad (3)$$

$$\begin{aligned}\text{Height} - 4.5 = {} & (S) * \{1 - \text{EXP}[-(c + d * S) * \text{Age}]\} ** f \\ & / \{1 - \text{EXP}[-(c + d * S) * 100]\} ** f \text{ , and}\end{aligned} \quad (4)$$

$$\begin{aligned}\text{Height} - 4.5 = {} & (S) * \{1 - \text{EXP}[-(c + d * S) * \text{Age}]\} ** (f * S) \\ & / \{1 - \text{EXP}[-(c + d * S) * 100]\} ** (f * S) \text{ ,}\end{aligned} \quad (5)$$

where all terms are as previously defined.

Equation (3) was used by Harrington and Curtis (1986) for height curves of red alder (*Alnus rubra* Bong.), and equations (4) and (5) were suggested by Robert O. Curtis[2] as useful alternatives. Equation (3) proved unsatisfactory because it produced troublesome negative numbers when age was at or near zero.

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[2] Personal communication, Robert O. Curtis, principal mensurationist, USDA Forest Service, Pacific Northwest Experiment Station, 3625 93d Ave. SW, Olympia, WA 98502.

Equation (5) produced results having higher mean deviations than those of equation (4), the one selected for a system of height-age curves for silver fir. (Variations of equations (4) and (5) using four coefficients were briefly examined but were judged of no greater value for the intended task than the three-coefficient forms used).

A System Based on Individual Tree Site Index (Alternative B)

Equation (4) was fitted to the original (nonsmoothed) individual tree values of height, age, and site index; the resulting coefficients and deviations from data were compared to other alternatives. Trees were weighted by the quantity 1/(square root of N) to account for geographic grouping of several trees per plot in group 1, whereas other trees were independent; N was number of trees grouped on a plot.

A System Based on Mean Plot Site Index (Alternative C)

Equation (4) was fitted to the original (nonsmoothed) height and age data; however, mean plot site index was used instead of individual tree site index.

Equations to Estimate Site Index

Site index, the average total height of the site trees at age 100 for each plot (group), was estimated from individual tree heights at all availible ages. In an alternative analysis, individual tree estimates of site index were also examined as a basis for an estimating equation.

Independent variables identified as likely predictors of site index were height, age, and many combinations and transformations of both. In addition, several lower bole height-increment variables were defined to gain greater precision for estimating site index from heights and ages below 20 years. These variables were heights at ages 5 and 10, both directly and in ratio form; height increment in the first 5 years; and height increment from 5 to 10 years. These variables also were used in transformed forms. The first bole cuts on the subject trees were often well above breast height, and the estimates of height at ages 5 and 10 years were made from smoothed lines between known points. Because of this, values of height at 5 and 10 years were used only as averages by tree group (plot) rather than on a tree-by-tree basis.

The variables were examined by using stepwise multiple regression as provided by SAS Institute, Inc. (1985). In addition, several transformations of site index and age were defined and examined as weighting factors used in regression analyses to maintain homogeneity of variance.

Correlation of Radial Growth With Height-Age Trends

A few of the sample trees classified earlier into the four groups of trees also had records of radial growth of annual rings at breast height. The number of sample trees were (1) free-growing trees—30 in group 1; (2) slightly retarded height growth—6 trees in group 2; and (3) severely retarded height growth—3 trees in group 3.

The radial growth measurements were the distance of 10 years of annual-ring growth, beginning at the outside of the tree into the pith. Fractions of 10 years, if any, were at the pith end of the cross section. These measurements had been scribed on Mylar; the original cross sections had not been saved.

About the first 60 years, from the pith outward, were used for analysis. Accumulated radial distance and the number of years were extracted from the Mylar record for each tree.

Diameter, height, and age at breast height when the tree was felled were also included as tree data. Based on a separate growth curve for each free-growing tree, smoothed heights were available at 5-year increments from age 5 to 60 and for site index age 100. When several trees shared the same plot, plot average site index was assigned.

To get an estimate of the potential site index of trees with retarded height growth, the free-growing (after release) section of the tree's later years was matched with the plotted trends of free-growing standard curves. (Remember that these trees with retarded height growth were dominant trees when they were selected for felling.) The height the tree would have reached at age 100 if it had been free-growing was assigned to the tree and used in this special analysis (but not, of course, in the main study of height growth and site index).

Analysis of Radial Growth

Prior evaluation showed clearly that the height attained by the trees at some age up to 40 could serve as an index to distinguish free-growing trees from those with retarded height growth. Age 20 was selected as a convenient, yet definitive, index age. Preliminary evaluation also showed that site index of the tree would influence diameter growth.

The question to be examined by this limited subset of the data was whether the core measurements and other appropriate data could be used to estimate height at age 20 and thereby distinguish the limits of the three defined groups of trees. The mean heights at age 20 for the groups were 23.0 feet for free-growing, 12.6 feet for slightly retarded, and 7.3 feet for severely retarded.

The accumulated inches of radius was estimated by years for each tree from the record of tree cross sections. An estimate of the radius at age 20 was computed for use in subsequent regression analyses.

A stepwise multiple regression analysis of the data (estimating height at age 20 from accumulated radial size at age 20, diameter, height, and age of tree) produced a simple linear regression.

Years Required to Reach Breast Height

The height-age trends of most of the free-growing trees were extended below breast height to age zero. A few trees had been long suppressed before they reached breast height; we did not use them to estimate the years required for free-growing trees to reach breast height. Years required to reach breast height were averaged for each plot and the results regressed on plot site index, height at age 100.

A sample of 18 young stands was measured in 1987. Years to breast height of three free-growing trees per stand were compared to estimated site index. Stands ranged in age from 5 to 25 years at breast height.

Results

Height-Growth Curves

The coefficients for equation (4) as developed for alternatives B and C did not differ much from each other. The value for coefficients for B were well within the confidence range of the coefficients for C.

Plotted residuals for the selected equation, alternative C are in figures 3 and 4. Equation coefficients had slightly less variation in ages below 100 than did alternative B, as shown in figure 5. Coefficients and confidence limits at the 95-percent level are as follows:

Coefficient	Value	Confidence		Limits
c	0.0071839	0.0061	to	0.0082
d	0.0000571	0.0000479	to	0.0000664
f	1.39005	1.334	to	1.445

Estimated height and the differences between estimated and actual height of each data point were calculated and plotted by age-class groups for each of the three alternatives, A, B, and C. Results were essentially the same and are illustrated in figure 5. Alternative A, the difference between smoothed plot averages and actual data points, can be considered as an estimate of variation free from any influence imposed by fitting a system of equations as in alternatives B and C. Mean height differences of alternatives B and C were slightly greater than those of A.

The coefficients for alternative C in equation (4) were selected for estimating height growth of silver fir. This was based on homogeneity of variance of residuals, and on low mean difference of errors, illustrated in figure 5. The height-age curves produced are listed in table 1 and shown in figure 6.

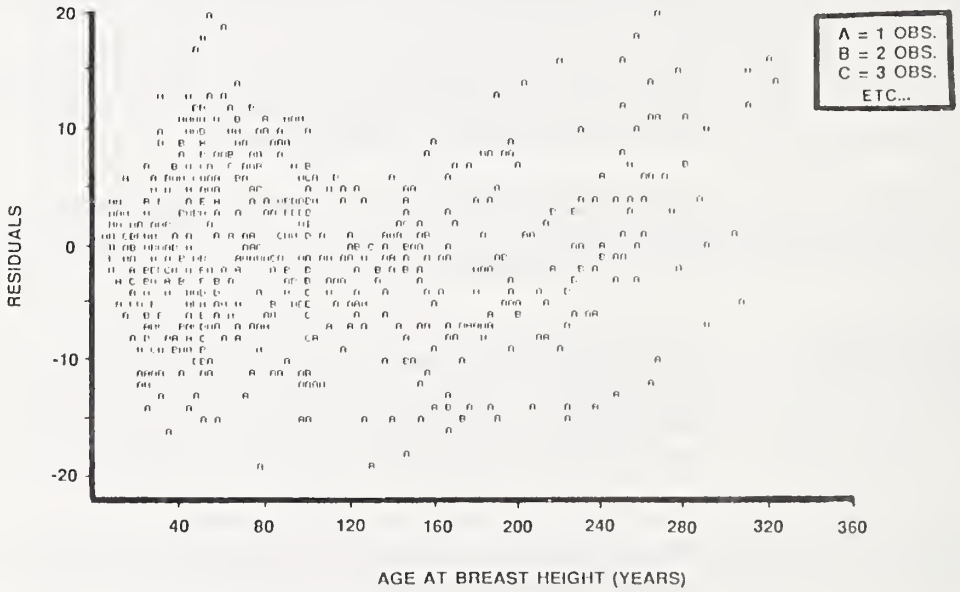

Figure 3—Plot of residuals over age for equation (4), alternative C.

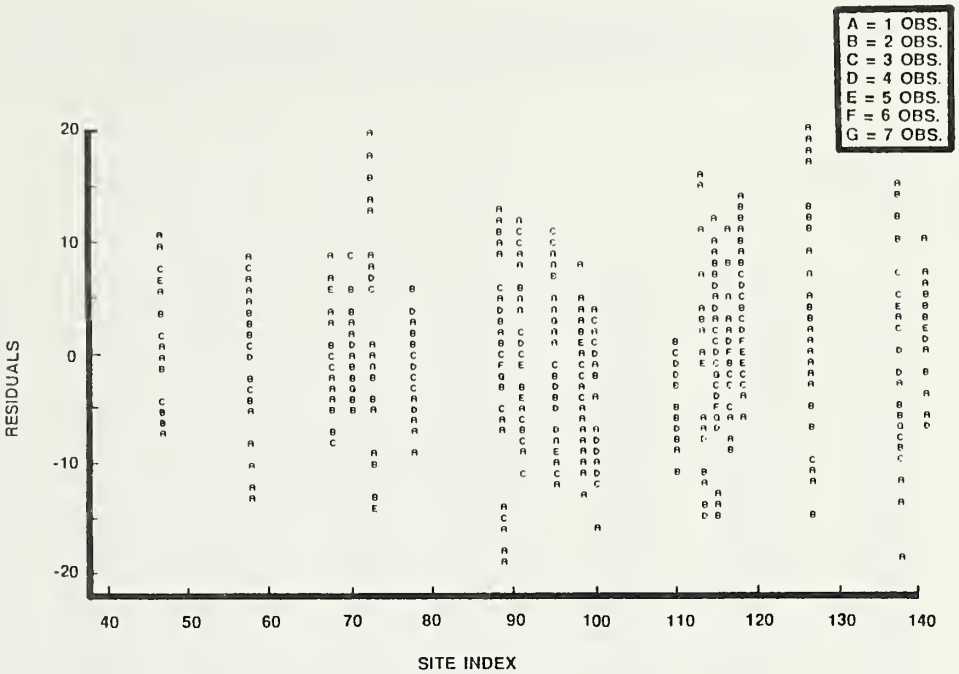

Figure 4—Plot of weighted residuals over site index for equation (4), alternative C.

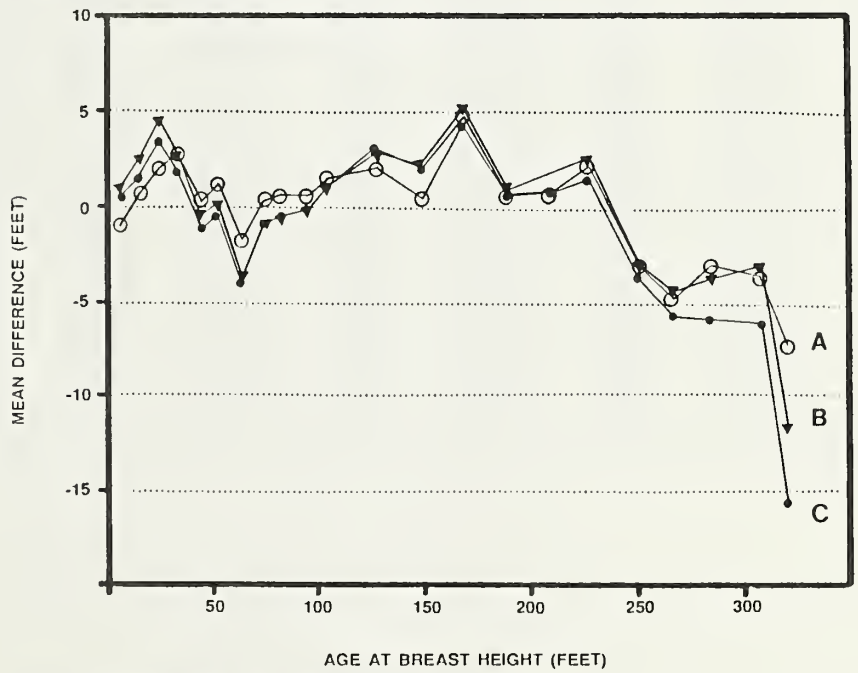

Figure 5—Mean difference between actual data and estimated height by age class groups for **(A)** equation (2) by plot; **(B)** equation (4) alternative B; and **(C)** equation (4), alternative C.

Table 1—Silver fir height, in feet, by age at breast height and site index[a]

BREAST HEIGHT AGE	SITE INDEX _40	_50	_60	_70	_80	_90	_100	_110	_120	BREAST HEIGHT AGE
5	5.5	5.8	6.1	6.5	6.8	7.2	7.6	8.1	8.5	5
10	7.0	7.7	8.6	9.4	10.4	11.3	12.3	13.4	14.5	10
15	8.7	10.0	11.4	12.9	14.4	16.0	17.7	19.5	21.3	15
20	10.5	12.4	14.4	16.5	18.7	21.0	23.4	25.8	28.4	20
25	12.5	15.0	17.6	20.3	23.1	26.1	29.2	32.4	35.7	25
30	14.5	17.6	20.8	24.1	27.6	31.2	35.0	38.9	42.9	30
35	16.5	20.2	24.0	28.0	32.1	36.4	40.8	45.3	50.0	35
40	18.5	22.8	27.2	31.8	36.5	41.4	46.4	51.6	56.9	40
45	20.5	25.4	30.4	35.5	40.9	46.3	52.0	57.7	63.6	45
50	22.5	27.9	33.5	39.2	45.1	51.1	57.3	63.6	70.1	50
55	24.4	30.4	36.5	42.8	49.2	55.8	62.5	69.3	76.3	55
60	26.4	32.8	39.5	46.3	53.2	60.2	67.4	74.8	82.2	60
65	28.2	35.2	42.4	49.6	57.0	64.6	72.2	80.0	87.9	65
70	30.1	37.5	45.2	52.9	60.7	68.7	76.8	85.0	93.3	70
80	33.6	42.0	50.5	59.1	67.7	76.5	85.3	94.2	103.2	80
90	36.9	46.1	55.4	64.8	74.1	83.6	93.0	102.5	112.1	90
100	40.0	50.0	60.0	70.0	80.0	90.0	100.0	110.0	120.0	100
110	42.9	53.6	64.2	74.8	85.3	95.8	106.3	116.7	127.0	110
120	45.6	56.9	68.1	79.2	90.2	101.1	111.9	122.6	133.2	120
130	48.1	60.0	71.7	83.2	94.6	105.8	116.9	127.9	138.7	130
140	50.4	62.8	74.9	86.8	98.5	110.0	121.4	132.5	143.5	140
150	52.6	65.4	77.9	90.1	102.1	113.8	125.3	136.7	147.8	150
160	54.6	67.8	80.6	93.1	105.3	117.2	128.9	140.3	151.5	160
170	56.4	69.9	83.0	95.8	108.2	120.2	132.0	143.5	154.8	170
180	58.1	71.9	85.3	98.2	110.8	122.9	134.8	146.4	157.7	180
190	59.6	73.7	87.3	100.4	113.1	125.4	137.3	148.9	160.2	190
200	61.1	75.4	89.2	102.4	115.2	127.5	139.5	151.1	162.4	200
220	63.6	78.3	92.4	105.8	118.7	131.1	143.1	154.7	165.9	220
240	65.7	80.7	95.0	108.6	121.5	134.0	146.0	157.5	168.7	240
260	67.4	82.7	97.1	110.8	123.8	136.3	148.2	159.7	170.8	260
280	68.9	84.4	98.9	112.6	125.6	138.0	149.9	161.4	172.4	280
300	70.2	85.7	100.3	114.1	127.1	139.4	151.3	162.6	173.6	300
320	71.2	86.9	101.5	115.2	128.2	140.5	152.3	163.6	174.5	320
340	72.1	87.8	102.4	116.2	129.1	141.4	153.1	164.4	175.2	340
360	72.8	88.6	103.2	116.9	129.9	142.1	153.8	165.0	175.7	360
380	73.4	89.2	103.8	117.5	130.4	142.6	154.3	165.4	176.1	380
400	73.9	89.7	104.4	118.0	130.9	143.1	154.7	165.8	176.5	400

[a] From equation 4, c.

Table 1—Silver fir height, in feet, by age at breast height and site index (continued)

	S I T E I N D E X								
BREAST HEIGHT AGE	_130	_140	_150	_160	_170	_180	_190	_200	BREAST HEIGHT AGE
5	9.0	9.5	10.0	10.5	11.1	11.7	12.3	12.9	5
10	15.7	16.9	18.2	19.5	20.8	22.3	23.8	25.3	10
15	23.2	25.2	27.3	29.4	31.7	34.0	36.4	38.9	15
20	31.1	33.9	36.8	39.7	42.8	46.0	49.4	52.8	20
25	39.1	42.6	46.3	50.1	54.0	58.1	62.2	66.5	25
30	47.0	51.3	55.7	60.3	65.0	69.8	74.8	79.9	30
35	54.8	59.8	64.9	70.2	75.6	81.2	86.8	92.7	35
40	62.4	68.0	73.8	79.7	85.8	92.0	98.3	104.8	40
45	69.7	75.9	82.3	88.8	95.5	102.3	109.2	116.3	45
50	76.7	83.5	90.4	97.5	104.7	112.0	119.4	127.0	50
55	83.4	90.7	98.1	105.7	113.3	121.1	129.0	137.1	55
60	89.8	97.6	105.4	113.4	121.5	129.7	138.0	146.4	60
65	95.9	104.0	112.3	120.7	129.1	137.7	146.4	155.1	65
70	101.7	110.2	118.8	127.5	136.3	145.1	154.1	163.2	70
80	112.3	121.4	130.6	139.8	149.2	158.6	168.0	177.5	80
90	121.7	131.3	140.9	150.6	160.4	170.1	179.9	189.7	90
100	130.0	140.0	150.0	160.0	170.0	180.0	190.0	200.0	100
110	137.3	147.6	157.9	168.1	178.3	188.5	198.6	208.7	110
120	143.8	154.3	164.7	175.1	185.4	195.7	205.9	216.0	120
130	149.5	160.1	170.7	181.1	191.5	201.8	212.0	222.2	130
140	154.4	165.2	175.8	186.3	196.7	207.0	217.2	227.3	140
150	158.7	169.5	180.2	190.7	201.1	211.4	221.6	231.7	150
160	162.5	173.4	184.0	194.5	204.9	215.1	225.2	235.3	160
170	165.8	176.7	187.3	197.8	208.1	218.3	228.3	238.3	170
180	168.7	179.5	190.1	200.6	210.8	220.9	230.9	240.8	180
190	171.2	182.0	192.6	202.9	213.1	223.2	233.1	242.9	190
200	173.4	184.1	194.6	205.0	215.1	225.1	234.9	244.7	200
220	176.9	187.6	198.0	208.2	218.2	228.1	237.8	247.3	220
240	179.5	190.1	200.4	210.5	220.4	230.2	239.7	249.2	240
260	181.6	192.0	202.2	212.2	222.0	231.7	241.1	250.5	260
280	183.1	193.4	203.6	213.5	223.2	232.7	242.1	251.4	280
300	184.2	194.5	204.5	214.4	224.0	233.5	242.8	252.0	300
320	185.0	195.3	205.3	215.0	224.6	234.0	243.3	252.5	320
340	185.7	195.9	205.8	215.5	225.0	234.4	243.6	252.8	340
360	186.2	196.3	206.2	215.8	225.3	234.6	243.9	253.0	360
380	186.5	196.6	206.5	216.1	225.5	234.8	244.0	253.1	380
400	186.8	196.9	206.7	216.3	225.7	235.0	244.1	253.2	400

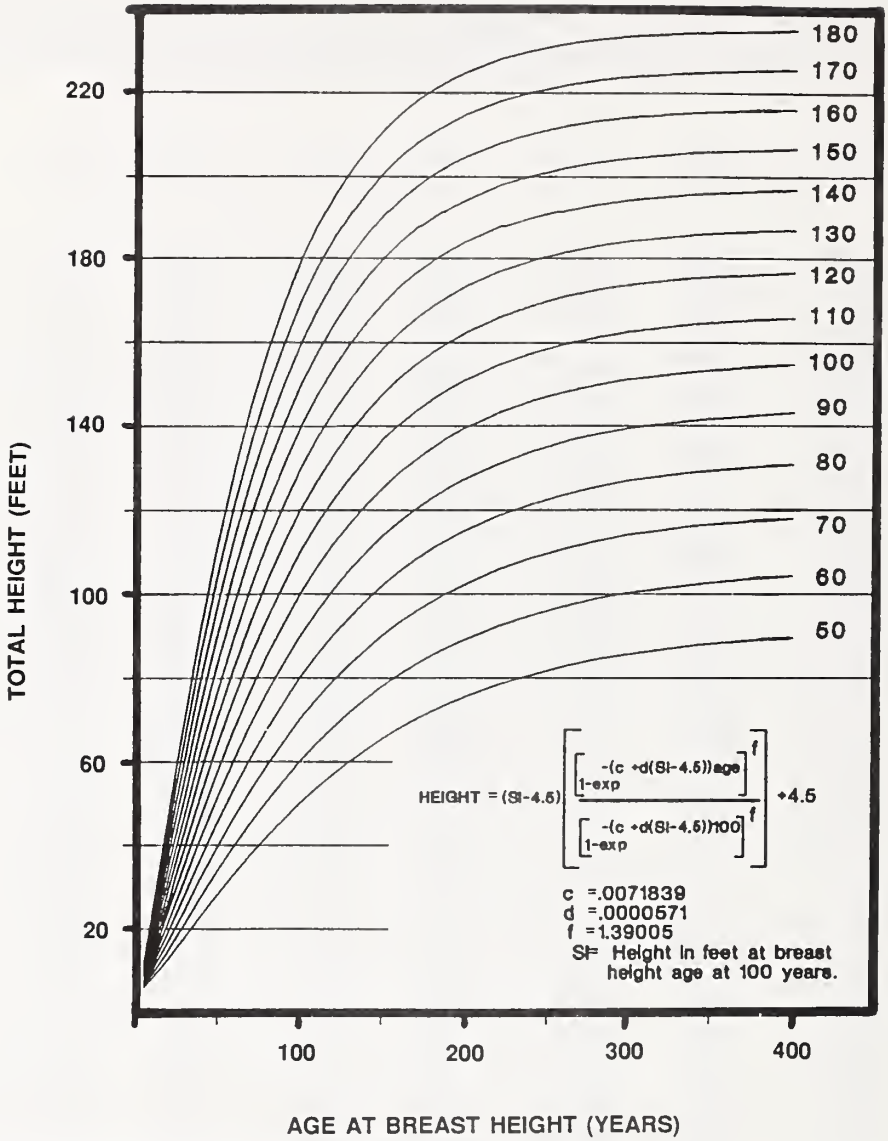

Figure 6—Height growth curves for Pacific silver fir.

Conversions Between Site Index at Base Ages 100 and 50

Some other tree species found with silver fir have site index relations based on age 50 years at breast height. Direct conversions are useful for changing index height at one age to index height at the other. For that purpose, the smoothed height-age curves produced by equation (4), alternative C, were used as the basis for regressing height at one index age to terms of height at the other. The following equations resulted:

$$H50 = 2.10 + 0.47937 * H100 + 0.000731 * (H100 ** 2) \text{ , and} \quad (6)$$

$$H100 = -1.08 + 1.908 * H50 - 0.002599 * (H50 ** 2) \text{ ,} \quad (7)$$

where H50 and H100 are heights in feet at breast height age 50 and 100 years, respectively, for the fitted height-age curves.

Site Index Equation

Using either mean plot (group) site index or individual tree site index produced equations with the same variables and nearly identical coefficients. The form of the selected equation was:

$$\begin{aligned} LN(SI/Height) = & -0.0268797 * (Age - 100) / Age \\ & + 0.0046259 * (Age - 100) **2 / 100 \\ & - 0.0015862 * (Age - 100) **3 / 10{,}000 \\ & - 0.0761453 * (Age - 100) / SQRT(Height) \\ & + 0.0891105 * (Age - 100) / Height \end{aligned} \quad (8)$$

where

SI = mean plot (group) total height at breast height age 100,
Age = age at breast height,
LN = logarithm (base e),
Height = total tree height at given Age, and
SQRT = the square root of a given variable.

All variables were significant at 0.005 level of probability or higher, and R-square was 0.98. Root mean square error was 0.178, and mean of the dependent variable was 0.448. Mean site index was 97.6. There were 650 observations.

Equation (8) was fitted by using, as a weight, the number of trees originally on a field plot (or group). Plots of the weighted residuals appear in figures 7 and 8. Equation results are in table 3 (appendix).

There was little effect from adding variables that estimated height and height growth near breast height to the variables in equation (8). Removing ages over 60 years from the data and refitting the variables in equation (8) with a height-growth variable near breast height increased the precision of fit significantly; however, the amount of increased precision was not considered worth the effort required to take the extra measurements near breast height.

Radial Increment and Height of Free-Growing Trees

A regression equation indicated that about half of the variation of tree height at age 20 could be accounted for by radial increment. This information along with plotted trends of data led to the following conclusions:

- Free-growing trees exceeded 20 feet of height by age 40 and were 14 feet tall or more by age 20. Exceptions were trees with sites index 50 and lower.

- Slightly retarded height growth occurred on trees exceeding 20 feet of height at age 40 but less than 14 feet at age 20.

- Trees with major height retardation in early years failed to reach 20 feet by age 40.

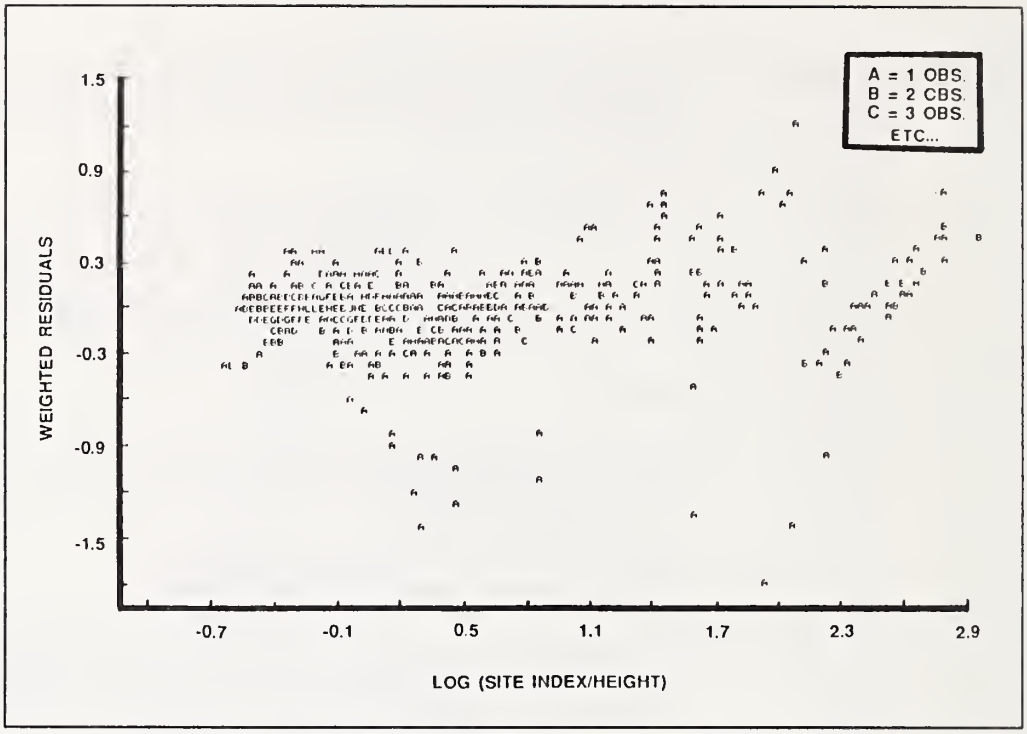

Figure 7—Plot of weighted residuals over log (site index/height) for equation (8).

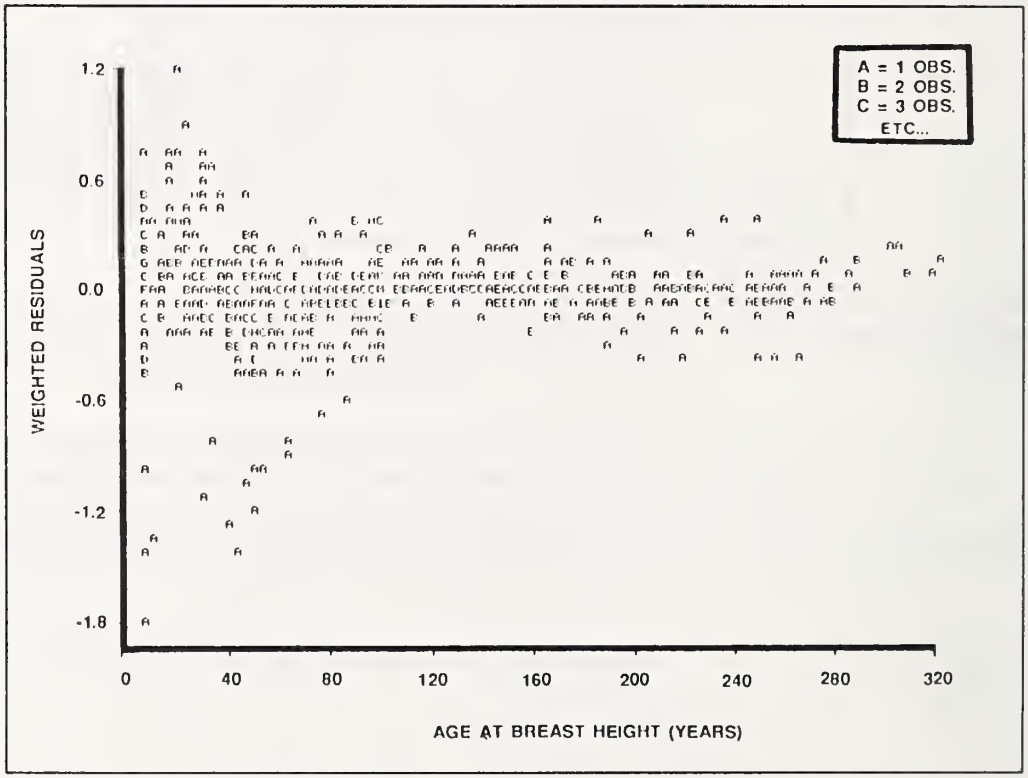

Figure 8—Plot of weighted residuals over age for equation (8).

Based on these findings and the limited help of several regression analysis trials, a general rule for defining nonfree-growing trees was formulated:

> All dominant trees whose (breast-height increment core boring) radius at 20 years from the pith was less than 0.9 inch had retarded height and diameter growth in early years and should not be used as a sample tree for site index.

Years Required to Reach Breast Height

The following equation estimates the number of years required to reach breast height as represented by the graphic extrapolation of the felled tree plots. Results are summarized in table 2.

$$\text{Years to breast height} = 21.35 - 0.1029 * SI\ , \qquad (9)$$

where SI is site index height at 100 years, R-square was 0.677, root mean square error was 2.6 feet, and 20 data points were used.

Results of equation (9) compared well with 18 young stands where site index was estimated from equation (8) and years to breast height was measured from free-growing sample trees. Plotted values of mean years to breast height and mean site index of the sample were within 1 year of the line described by equation (9). This was considered verification of the usefulness of equation (9).

Discussion

Height-Growth Curves

Either of the two approaches used here—using individual tree site index or using mean site index representing groups of trees—produced adequate estimates of tree height up to age 250 (fig. 5). Large deviations in estimates at ages greater than 250 were the result of inadequate data. The results gave no support to the intuitive concern that site index height might be inadequately estimated by single tree samples. Average differences for alternatives B and C (fig. 5) were only slightly greater than for alternative A, which was considered an estimate of natural variation of trees examined within individual groups (plots).

Estimating Site Index

Even though the data reached 250 years, a main interest of the analysis was to provide estimating equations for use in young second-growth silver fir. The graphic analysis indicated relatively stable trends. Equation (8) estimated mean site index with a range of ± 15 feet throughout the range of sites in the data.

Adding the variables specifying height growth and height ratios at ages 5 and 10 years above breast height gave increased precision to estimates of site index that were otherwise limited to current tree age and height. The increased precision was not of practical use. It is expected that if index age were redefined to age 50 then the added variables near breast height might have practical significance. Further work along this line was beyond the scope of this study.

Radial Increment of Free-Growing Trees

Only free-growing trees must be used for estimating site index. A careful sample selection from among the dominant and codominant trees in even-aged stands will probably exclude most nonfree-growing trees. As a final test though, ring growth on increment cores of presumed free-growing trees should be checked, and the general rule devised here should be applied.

Acknowledgments

We acknowledge the advice and counsel provided at several important times during project planning and analysis by Robert O. Curtis, principal mensurationist, Pacific Northwest Research Station, Olympia, Washington.

Metric Equivalents

1 foot = 0.3048 meter
1 inch = 2.54 centimeters
Breast height = 4.5 feet = 1.37 meters above ground
40 largest trees per acre = 100 largest trees per hectare

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Appendix

Table 2—Height at age 50 and years to breast height for site index based at 100 years breast height

Site index age 100	Height at age 50[a]	Years to breast height[b]
	Feet	
40	22.5	17
50	27.9	16
60	33.5	15
70	39.2	14
80	45.1	13
90	51.1	12
100	57.3	11
110	63.6	10
120	70.1	9
130	76.7	8
140	83.5	7
150	90.4	5
160	97.5	4
170	104.7	3
180	112.0	2
190	119.4	2
200	127.0	2

[a] From equation (6).
[b] From equation (9).

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a]

					H E I G H T						
BREAST HEIGHT AGE	_40	_42	_44	_46	_48	_50	_52	_54	_56	_58	_60	BREAST HEIGHT AGE
9	205											9
10	193	200										10
11	184	190	196									11
12	176	182	188	193	199							12
13	169	175	180	186	191	197						13
14	163	168	174	179	184	190	195	200				14
15	157	163	168	173	178	183	188	193	198			15
16	152	157	163	168	173	177	182	187	192	197		16
17	148	153	158	163	167	172	177	182	186	191	196	17
18	143	148	153	158	163	167	172	177	181	186	190	18
19	139	144	149	154	158	163	167	172	176	181	185	19
20	136	140	145	150	154	159	163	168	172	176	181	20
21	132	137	141	146	150	155	159	163	168	172	176	21
22	129	133	138	142	147	151	155	160	164	168	172	22
23	126	130	135	139	143	147	152	156	160	164	168	23
24	123	127	131	136	140	144	148	152	156	161	165	24
25	120	124	128	133	137	141	145	149	153	157	161	25
26	117	121	126	130	134	138	142	146	150	154	158	26
27	115	119	123	127	131	135	139	143	147	151	154	27
28	112	116	120	124	128	132	136	140	144	148	151	28
29	110	114	118	122	126	129	133	137	141	145	148	29
30	108	112	115	119	123	127	131	134	138	142	146	30
31	105	109	113	117	121	124	128	132	135	139	143	31
32	103	107	111	115	118	122	126	129	133	137	140	32
33	101	105	109	112	116	120	123	127	130	134	138	33
34	99	103	107	110	114	118	121	125	128	132	135	34
35	97	101	105	108	112	115	119	122	126	129	133	35
36	96	99	103	106	110	113	117	120	124	127	130	36
37	94	97	101	104	108	111	115	118	122	125	128	37
38	92	96	99	103	106	109	113	116	119	123	126	38
39	90	94	97	101	104	107	111	114	117	121	124	39
40	89	92	96	99	102	106	109	112	115	119	122	40
41	87	91	94	97	101	104	107	110	114	117	120	41
42	86	89	92	96	99	102	105	109	112	115	118	42
43	84	88	91	94	97	101	104	107	110	113	116	43
44	83	86	89	93	96	99	102	105	108	111	114	44
45	82	85	88	91	94	97	100	104	107	110	113	45
46	80	83	86	90	93	96	99	102	105	108	111	46
47	79	82	85	88	91	94	97	100	103	106	109	47
48	78	81	84	87	90	93	96	99	102	105	108	48
49	76	79	82	85	88	91	94	97	100	103	106	49
50	75	78	81	84	87	90	93	96	99	102	105	50
51	74	77	80	83	86	89	92	95	97	100	103	51
52	73	76	79	82	85	87	90	93	96	99	102	52
53	72	75	78	80	83	86	89	92	95	97	100	53
54	71	74	76	79	82	85	88	91	93	96	99	54
55	70	72	75	78	81	84	87	89	92	95	98	55
56	69	71	74	77	80	83	85	88	91	94	96	56
57	67	70	73	76	79	81	84	87	90	92	95	57
58	67	69	72	75	78	80	83	86	88	91	94	58
59	66	68	71	74	76	79	82	85	87	90	93	59
60	65	67	70	73	75	78	81	83	86	89	91	60
61	64	66	69	72	74	77	80	82	85	88	90	61

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_40	_42	_44	_46	_48	_50	_52	_54	_56	_58	_60	BREAST HEIGHT AGE
62	63	65	68	71	73	76	79	81	84	86	89	62
63	62	65	67	70	72	75	78	80	83	85	88	63
64	61	64	66	69	72	74	77	79	82	84	87	64
65	60	63	65	68	71	73	76	78	81	83	86	65
66	59	62	65	67	70	72	75	77	80	82	85	66
67	59	61	64	66	69	71	74	76	79	81	84	67
68	58	60	63	65	68	70	73	75	78	80	83	68
69	57	60	62	65	67	70	72	74	77	79	82	69
70	56	59	61	64	66	69	71	74	76	78	81	70
72	55	57	60	62	65	67	69	72	74	77	79	72
74	54	56	58	61	63	65	68	70	73	75	77	74
76	52	55	57	59	62	64	66	69	71	73	76	76
78	51	53	56	58	60	63	65	67	69	72	74	78
80	50	52	54	57	59	61	63	66	68	70	72	80
82	49	51	53	55	58	60	62	64	67	69	71	82
84	47	50	52	54	56	59	61	63	65	67	70	84
86	46	49	51	53	55	57	60	62	64	66	68	86
88	45	48	50	52	54	56	58	60	63	65	67	88
90	44	47	49	51	53	55	57	59	61	64	66	90
92	43	46	48	50	52	54	56	58	60	62	64	92
94	43	45	47	49	51	53	55	57	59	61	63	94
96	42	44	46	48	50	52	54	56	58	60	62	96
98	41	43	45	47	49	51	53	55	57	59	61	98
100	40	42	44	46	48	50	52	54	56	58	60	100
105	38	40	42	44	46	48	50	52	54	56	58	105
110	36	38	40	42	44	46	48	50	52	53	55	110
115	35	37	38	40	42	44	46	48	50	51	53	115
120	33	35	37	39	41	42	44	46	48	50	51	120
125	32	34	35	37	39	41	43	44	46	48	50	125
130	31	32	34	36	38	39	41	43	45	46	48	130
135	30	31	33	35	36	38	40	41	43	45	47	135
140	28	30	32	33	35	37	39	40	42	44	45	140
145	27	29	31	32	34	36	37	39	41	42	44	145
150	27	28	30	31	33	35	36	38	40	41	43	150
155	26	27	29	30	32	34	35	37	39	40	42	155
160	25	26	28	30	31	33	34	36	38	39	41	160
165	24	26	27	29	30	32	33	35	37	38	40	165
170	23	25	26	28	29	31	33	34	36	37	39	170

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

BREAST HEIGHT AGE	HEIGHT _60	_62	_64	_66	_68	_70	_72	_74	_76	_78	_80	BREAST HEIGHT AGE
15	208	213										15
16	202	206										16
17	196	201	205									17
18	190	195	200	204	209							18
19	185	190	194	199	203	207	212					19
20	181	185	189	194	198	202	207	211				20
21	176	181	185	189	193	198	202	206	210			21
22	172	176	181	185	189	193	197	201	205	209		22
23	168	172	176	181	185	189	193	197	201	205	209	23
24	165	169	173	177	181	185	189	192	196	200	204	24
25	161	165	169	173	177	181	185	188	192	196	200	25
26	158	162	165	169	173	177	181	185	188	192	196	26
27	154	158	162	166	170	173	177	181	185	188	192	27
28	151	155	159	163	166	170	174	177	181	185	188	28
29	148	152	156	159	163	167	170	174	178	181	185	29
30	146	149	153	156	160	164	167	171	174	178	182	30
31	143	146	150	154	157	161	164	168	171	175	178	31
32	140	144	147	151	154	158	161	165	168	172	175	32
33	138	141	145	148	152	155	158	162	165	169	172	33
34	135	139	142	145	149	152	156	159	163	166	169	34
35	133	136	140	143	146	150	153	156	160	163	166	35
36	130	134	137	141	144	147	151	154	157	160	164	36
37	128	132	135	138	142	145	148	151	155	158	161	37
38	126	129	133	136	139	142	146	149	152	155	159	38
39	124	127	130	134	137	140	143	147	150	153	156	39
40	122	125	128	132	135	138	141	144	147	151	154	40
41	120	123	126	130	133	136	139	142	145	148	151	41
42	118	121	124	127	131	134	137	140	143	146	149	42
43	116	119	122	126	129	132	135	138	141	144	147	43
44	114	118	121	124	127	130	133	136	139	142	145	44
45	113	116	119	122	125	128	131	134	137	140	143	45
46	111	114	117	120	123	126	129	132	135	138	141	46
47	109	112	115	118	121	124	127	130	133	136	139	47
48	108	111	114	117	119	122	125	128	131	134	137	48
49	106	109	112	115	118	121	124	126	129	132	135	49
50	105	108	110	113	116	119	122	125	127	130	133	50
51	103	106	109	112	115	117	120	123	126	129	131	51
52	102	105	107	110	113	116	119	121	124	127	130	52
53	100	103	106	109	111	114	117	120	122	125	128	53
54	99	102	104	107	110	113	115	118	121	124	126	54
55	98	100	103	106	109	111	114	117	119	122	125	55
56	96	99	102	104	107	110	112	115	118	120	123	56
57	95	98	100	103	106	108	111	114	116	119	122	57
58	94	96	99	102	104	107	110	112	115	118	120	58
59	93	95	98	100	103	106	108	111	113	116	119	59
60	91	94	97	99	102	104	107	110	112	115	117	60
61	90	93	95	98	101	103	106	108	111	113	116	61
62	89	92	94	97	99	102	104	107	109	112	115	62
63	88	90	93	96	98	101	103	106	108	111	113	63
64	87	89	92	94	97	99	102	104	107	109	112	64
65	86	88	91	93	96	98	101	103	106	108	111	65
66	85	87	90	92	95	97	100	102	105	107	109	66
67	84	86	89	91	94	96	99	101	103	106	108	67

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T							
BREAST HEIGHT AGE	_60	_62	_64	_66	_68	_70	_72	_74	_76	_78	_80	BREAST HEIGHT AGE
68	83	85	88	90	93	95	97	100	102	105	107	68
69	82	84	87	89	91	94	96	99	101	104	106	69
70	81	83	86	88	90	93	95	98	100	102	105	70
72	79	81	84	86	89	91	93	96	98	100	103	72
74	77	80	82	84	87	89	91	94	96	98	101	74
76	76	78	80	83	85	87	89	92	94	96	99	76
78	74	76	79	81	83	85	88	90	92	94	97	78
80	72	75	77	79	81	84	86	88	90	93	95	80
82	71	73	75	78	80	82	84	86	89	91	93	82
84	70	72	74	76	78	80	83	85	87	89	91	84
86	68	70	73	75	77	79	81	83	85	88	90	86
88	67	69	71	73	75	78	80	82	84	86	88	88
90	66	68	70	72	74	76	78	80	82	85	87	90
92	64	66	69	71	73	75	77	79	81	83	85	92
94	63	65	67	69	71	74	76	78	80	82	84	94
96	62	64	66	68	70	72	74	76	78	80	83	96
98	61	63	65	67	69	71	73	75	77	79	81	98
100	60	62	64	66	68	70	72	74	76	78	80	100
105	58	60	61	63	65	67	69	71	73	75	77	105
110	55	57	59	61	63	65	67	69	71	73	74	110
115	53	55	57	59	61	63	65	66	68	70	72	115
120	51	53	55	57	59	61	62	64	66	68	70	120
125	50	52	53	55	57	59	61	62	64	66	68	125
130	48	50	52	53	55	57	59	61	62	64	66	130
135	47	48	50	52	54	55	57	59	61	63	64	135
140	45	47	49	51	52	54	56	58	59	61	63	140
145	44	46	47	49	51	53	54	56	58	60	61	145
150	43	45	46	48	50	51	53	55	57	58	60	150
155	42	43	45	47	49	50	52	54	55	57	59	155
160	41	42	44	46	47	49	51	52	54	56	58	160
165	40	41	43	45	46	48	50	51	53	55	57	165
170	39	41	42	44	45	47	49	50	52	54	55	170
175	38	40	41	43	45	46	48	50	51	53	55	175
180	37	39	40	42	44	45	47	49	50	52	54	180
185	37	38	40	41	43	45	46	48	49	51	53	185
190	36	37	39	40	42	44	45	47	49	50	52	190
195	35	37	38	40	41	43	45	46	48	49	51	195
200	34	36	37	39	41	42	44	45	47	49	50	200
250	28	29	31	32	34	35	37	38	40	41	43	250

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_80	_82	_84	_86	_88	_90	_92	_94	_96	_98	_100	BREAST HEIGHT AGE
20												20
21												21
22												22
23												23
24	204											24
25	200											25
26	196	200										26
27	192	196	200									27
28	188	192	196	199								28
29	185	189	192	196	199							29
30	182	185	189	192	196	199						30
31	178	182	185	189	192	196	199					31
32	175	179	182	185	189	192	196	199				32
33	172	176	179	182	186	189	192	196	199			33
34	169	173	176	179	183	186	189	193	196	199	202	34
35	166	170	173	176	180	183	186	189	193	196	199	35
36	164	167	170	173	177	180	183	186	190	193	196	36
37	161	164	168	171	174	177	180	184	187	190	193	37
38	159	162	165	168	171	174	178	181	184	187	190	38
39	156	159	162	165	169	172	175	178	181	184	187	39
40	154	157	160	163	166	169	172	175	178	181	184	40
41	151	154	157	161	164	167	170	173	176	179	182	41
42	149	152	155	158	161	164	167	170	173	176	179	42
43	147	150	153	156	159	162	165	168	171	174	177	43
44	145	148	151	154	157	160	163	165	168	171	174	44
45	143	146	149	151	154	157	160	163	166	169	172	45
46	141	144	146	149	152	155	158	161	164	167	170	46
47	139	142	144	147	150	153	156	159	162	164	167	47
48	137	140	142	145	148	151	154	157	159	162	165	48
49	135	138	141	143	146	149	152	155	157	160	163	49
50	133	136	139	141	144	147	150	153	155	158	161	50
51	131	134	137	140	142	145	148	151	153	156	159	51
52	130	132	135	138	141	143	146	149	151	154	157	52
53	128	131	133	136	139	141	144	147	150	152	155	53
54	126	129	132	134	137	140	142	145	148	150	153	54
55	125	127	130	133	135	138	141	143	146	149	151	55
56	123	126	128	131	134	136	139	142	144	147	149	56
57	122	124	127	129	132	135	137	140	143	145	148	57
58	120	123	125	128	131	133	136	138	141	143	146	58
59	119	121	124	126	129	132	134	137	139	142	144	59
60	117	120	122	125	127	130	133	135	138	140	143	60
61	116	118	121	123	126	129	131	134	136	139	141	61
62	115	117	120	122	125	127	130	132	135	137	140	62
63	113	116	118	121	123	126	128	131	133	136	138	63
64	112	114	117	119	122	124	127	129	132	134	137	64
65	111	113	116	118	120	123	125	128	130	133	135	65
66	109	112	114	117	119	122	124	126	129	131	134	66
67	108	111	113	116	118	120	123	125	128	130	132	67
68	107	109	112	114	117	119	121	124	126	129	131	68
69	106	108	111	113	115	118	120	123	125	127	130	69
70	105	107	110	112	114	117	119	121	124	126	128	70
72	103	105	107	110	112	114	117	119	121	124	126	72
74	101	103	105	107	110	112	114	117	119	121	123	74

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

BREAST HEIGHT AGE	H E I G H T _80	_82	_84	_86	_88	_90	_92	_94	_96	_98	_100	BREAST HEIGHT AGE
76	99	101	103	105	108	110	112	114	117	119	121	76
78	97	99	101	103	106	108	110	112	115	117	119	78
80	95	97	99	101	104	106	108	110	112	115	117	80
82	93	95	97	100	102	104	106	108	111	113	115	82
84	91	94	96	98	100	102	104	106	109	111	113	84
86	90	92	94	96	98	100	103	105	107	109	111	86
88	88	90	92	95	97	99	101	103	105	107	109	88
90	87	89	91	93	95	97	99	101	103	106	108	90
92	85	87	89	91	94	96	98	100	102	104	106	92
94	84	86	88	90	92	94	96	98	100	102	104	94
96	83	85	87	89	91	93	95	97	99	101	103	96
98	81	83	85	87	89	91	93	95	97	99	101	98
100	80	82	84	86	88	90	92	94	96	98	100	100
105	77	79	81	83	85	87	89	91	93	95	97	105
110	74	76	78	80	82	84	86	88	90	92	94	110
115	72	74	76	78	80	82	83	85	87	89	91	115
120	70	72	74	75	77	79	81	83	85	87	89	120
125	68	70	72	73	75	77	79	81	83	84	86	125
130	66	68	70	71	73	75	77	79	81	82	84	130
135	64	66	68	70	72	73	75	77	79	81	82	135
140	63	65	66	68	70	72	73	75	77	79	81	140
145	61	63	65	67	68	70	72	74	75	77	79	145
150	60	62	63	65	67	69	70	72	74	76	78	150
155	59	60	62	64	66	67	69	71	73	74	76	155
160	58	59	61	63	64	66	68	70	71	73	75	160
165	57	58	60	62	63	65	67	69	70	72	74	165
170	55	57	59	61	62	64	66	67	69	71	73	170
175	55	56	58	60	61	63	65	66	68	70	72	175
180	54	55	57	59	60	62	64	66	67	69	71	180
185	53	54	56	58	59	61	63	65	66	68	70	185
190	52	54	55	57	59	60	62	64	65	67	69	190
195	51	53	54	56	58	60	61	63	65	66	68	195
200	50	52	54	55	57	59	60	62	64	66	67	200
250	43	45	46	48	49	51	53	54	56	58	59	250
300	34	35	37	38	40	41	42	44	45	47	48	300

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T							
BREAST HEIGHT AGE	_100	_102	_104	_106	_108	_110	_112	_114	_116	_118	_120	BREAST HEIGHT AGE
28												28
29												29
30												30
31												31
32												32
33	206											33
34	202	206										34
35	199	202	206									35
36	196	199	202	206								36
37	193	196	199	202	206							37
38	190	193	196	199	203	206						38
39	187	190	193	196	200	203	206					39
40	184	188	191	194	197	200	203	206				40
41	182	185	188	191	194	197	200	203	206			41
42	179	182	185	188	191	194	197	200	203	206		42
43	177	180	183	186	188	191	194	197	200	203	206	43
44	174	177	180	183	186	189	192	195	197	200	203	44
45	172	175	178	181	183	186	189	192	195	198	201	45
46	170	172	175	178	181	184	187	189	192	195	198	46
47	167	170	173	176	179	181	184	187	190	193	195	47
48	165	168	171	173	176	179	182	185	187	190	193	48
49	163	166	168	171	174	177	180	182	185	188	191	49
50	161	164	166	169	172	175	177	180	183	185	188	50
51	159	162	164	167	170	172	175	178	181	183	186	51
52	157	160	162	165	168	170	173	176	178	181	184	52
53	155	158	160	163	166	168	171	174	176	179	182	53
54	153	156	158	161	164	166	169	172	174	177	179	54
55	151	154	156	159	162	164	167	170	172	175	177	55
56	149	152	155	157	160	162	165	168	170	173	175	56
57	148	150	153	155	158	161	163	166	168	171	173	57
58	146	149	151	154	156	159	161	164	166	169	171	58
59	144	147	149	152	154	157	160	162	165	167	170	59
60	143	145	148	150	153	155	158	160	163	165	168	60
61	141	144	146	149	151	154	156	159	161	164	166	61
62	140	142	145	147	149	152	154	157	159	162	164	62
63	138	141	143	145	148	150	153	155	158	160	163	63
64	137	139	141	144	146	149	151	154	156	158	161	64
65	135	138	140	142	145	147	150	152	154	157	159	65
66	134	136	139	141	143	146	148	151	153	155	158	66
67	132	135	137	140	142	144	147	149	151	154	156	67
68	131	133	136	138	140	143	145	148	150	152	155	68
69	130	132	134	137	139	141	144	146	148	151	153	69
70	128	131	133	135	138	140	142	145	147	149	152	70
72	126	128	130	133	135	137	140	142	144	147	149	72
74	123	126	128	130	133	135	137	139	142	144	146	74
76	121	123	126	128	130	132	135	137	139	141	144	76
78	119	121	123	126	128	130	132	135	137	139	141	78
80	117	119	121	123	126	128	130	132	134	137	139	80
82	115	117	119	121	124	126	128	130	132	134	137	82
84	113	115	117	119	122	124	126	128	130	132	134	84
86	111	113	115	117	120	122	124	126	128	130	132	86
88	109	111	114	116	118	120	122	124	126	128	130	88
90	108	110	112	114	116	118	120	122	124	126	128	90

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T							
BREAST HEIGHT AGE	_100	_102	_104	_106	_108	_110	_112	_114	_116	_118	_120	BREAST HEIGHT AGE
92	106	108	110	112	114	116	118	120	123	125	127	92
94	104	106	108	111	113	115	117	119	121	123	125	94
96	103	105	107	109	111	113	115	117	119	121	123	96
98	101	103	105	107	109	111	113	116	118	120	122	98
100	100	102	104	106	108	110	112	114	116	118	120	100
105	97	99	101	103	105	107	109	110	112	114	116	105
110	94	96	98	100	101	103	105	107	109	111	113	110
115	91	93	95	97	99	101	102	104	106	108	110	115
120	89	90	92	94	96	98	100	102	104	105	107	120
125	86	88	90	92	94	96	97	99	101	103	105	125
130	84	86	88	90	92	93	95	97	99	101	103	130
135	82	84	86	88	90	91	93	95	97	99	101	135
140	81	82	84	86	88	90	91	93	95	97	99	140
145	79	81	83	84	86	88	90	92	93	95	97	145
150	78	79	81	83	85	86	88	90	92	94	95	150
155	76	78	80	82	83	85	87	89	90	92	94	155
160	75	77	78	80	82	84	86	87	89	91	93	160
165	74	76	77	79	81	83	84	86	88	90	92	165
170	73	74	76	78	80	81	83	85	87	89	90	170
175	72	73	75	77	79	80	82	84	86	88	89	175
180	71	72	74	76	78	79	81	83	85	87	88	180
185	70	72	73	75	77	79	80	82	84	86	87	185
190	69	71	72	74	76	78	79	81	83	85	87	190
195	68	70	72	73	75	77	79	80	82	84	86	195
200	67	69	71	73	74	76	78	80	81	83	85	200
250	59	61	63	65	66	68	70	72	73	75	77	250
300	48	50	52	53	55	56	58	59	61	63	64	300

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_120	_122	_124	_126	_128	_130	_132	_134	_136	_138	_140	BREAST HEIGHT AGE
40												40
41												41
42												42
43	206											43
44	203	206										44
45	201	203	206									45
46	198	201	204	206								46
47	195	198	201	204	207							47
48	193	196	198	201	204	207						48
49	191	193	196	199	201	204	207					49
50	188	191	194	196	199	202	204	207				50
51	186	189	191	194	197	199	202	205	207			51
52	184	186	189	192	194	197	200	202	205	208		52
53	182	184	187	189	192	195	197	200	203	205	208	53
54	179	182	185	187	190	192	195	198	200	203	205	54
55	177	180	183	185	188	190	193	195	198	201	203	55
56	175	178	180	183	186	188	191	193	196	198	201	56
57	173	176	178	181	184	186	189	191	194	196	199	57
58	171	174	177	179	182	184	187	189	192	194	197	58
59	170	172	175	177	180	182	185	187	190	192	195	59
60	168	170	173	175	178	180	183	185	188	190	193	60
61	166	168	171	173	176	178	181	183	186	188	191	61
62	164	167	169	172	174	177	179	181	184	186	189	62
63	163	165	167	170	172	175	177	180	182	184	187	63
64	161	163	166	168	171	173	175	178	180	183	185	64
65	159	162	164	166	169	171	174	176	178	181	183	65
66	158	160	162	165	167	170	172	174	177	179	181	66
67	156	159	161	163	166	168	170	173	175	177	180	67
68	155	157	159	162	164	166	169	171	173	176	178	68
69	153	155	158	160	162	165	167	169	172	174	176	69
70	152	154	156	159	161	163	166	168	170	173	175	70
72	149	151	153	156	158	160	163	165	167	169	172	72
74	146	148	151	153	155	158	160	162	164	167	169	74
76	144	146	148	150	153	155	157	159	162	164	166	76
78	141	143	146	148	150	152	154	157	159	161	163	78
80	139	141	143	145	148	150	152	154	156	159	161	80
82	137	139	141	143	145	147	150	152	154	156	158	82
84	134	137	139	141	143	145	147	149	152	154	156	84
86	132	134	137	139	141	143	145	147	149	151	154	86
88	130	132	135	137	139	141	143	145	147	149	151	88
90	128	131	133	135	137	139	141	143	145	147	149	90
92	127	129	131	133	135	137	139	141	143	145	147	92
94	125	127	129	131	133	135	137	139	141	143	145	94
96	123	125	127	129	131	133	135	137	139	141	143	96
98	122	124	126	128	130	132	134	136	138	140	142	98
100	120	122	124	126	128	130	132	134	136	138	140	100
105	116	118	120	122	124	126	128	130	132	134	136	105
110	113	115	117	119	121	123	125	127	129	131	132	110
115	110	112	114	116	118	120	122	123	125	127	129	115
120	107	109	111	113	115	117	119	121	122	124	126	120
125	105	107	109	110	112	114	116	118	120	122	124	125
130	103	104	106	108	110	112	114	116	117	119	121	130
135	101	102	104	106	108	110	112	113	115	117	119	135
140	99	101	102	104	106	108	110	112	113	115	117	140
145	97	99	101	102	104	106	108	110	112	113	115	145
150	95	97	99	101	103	105	106	108	110	112	114	150
155	94	96	98	99	101	103	105	107	109	110	112	155
160	93	95	96	98	100	102	104	105	107	109	111	160
165	92	93	95	97	99	101	102	104	106	108	110	165
170	90	92	94	96	98	99	101	103	105	107	108	170
175	89	91	93	95	97	98	100	102	104	106	107	175
180	88	90	92	94	96	97	99	101	103	105	107	180
185	87	89	91	93	95	96	98	100	102	104	106	185
190	87	88	90	92	94	96	97	99	101	103	105	190
195	86	88	89	91	93	95	97	98	100	102	104	195
200	85	87	89	90	92	94	96	98	100	101	103	200
250	77	79	80	82	84	86	88	90	92	93	95	250
300	64	66	68	69	71	73	74	76	78	80	81	300

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_140	_142	_144	_146	_148	_150	_152	_154	_156	_158	_160	BREAST HEIGHT AGE
50												50
51												51
52	210											52
53	208											53
54	205	208										54
55	203	206	208									55
56	201	204	206	209								56
57	199	201	204	206	209							57
58	197	199	202	204	207	209						58
59	195	197	200	202	205	207	210					59
60	193	195	198	200	202	205	207					60
61	191	193	196	198	200	203	205	208				61
62	189	191	194	196	198	201	203	206	208	211		62
63	187	189	192	194	197	199	201	204	206	209		63
64	185	187	190	192	195	197	199	202	204	207	209	64
65	183	186	188	190	193	195	197	200	202	205	207	65
66	181	184	186	189	191	193	196	198	200	203	205	66
67	180	182	184	187	189	192	194	196	199	201	203	67
68	178	180	183	185	187	190	192	194	197	199	201	68
69	176	179	181	183	186	188	190	193	195	197	200	69
70	175	177	179	182	184	186	189	191	193	196	198	70
72	172	174	176	179	181	183	185	188	190	192	195	72
74	169	171	173	176	178	180	182	185	187	189	191	74
76	166	168	170	173	175	177	179	182	184	186	188	76
78	163	165	168	170	172	174	176	179	181	183	185	78
80	161	163	165	167	169	172	174	176	178	180	182	80
82	158	160	163	165	167	169	171	173	175	178	180	82
84	156	158	160	162	164	167	169	171	173	175	177	84
86	154	156	158	160	162	164	166	168	170	173	175	86
88	151	153	156	158	160	162	164	166	168	170	172	88
90	149	151	153	156	158	160	162	164	166	168	170	90
92	147	149	151	153	155	158	160	162	164	166	168	92
94	145	147	149	151	154	156	158	160	162	164	166	94
96	143	146	148	150	152	154	156	158	160	162	164	96
98	142	144	146	148	150	152	154	156	158	160	162	98
100	140	142	144	146	148	150	152	154	156	158	160	100
105	136	138	140	142	144	146	148	150	152	154	156	105
110	132	134	136	138	140	142	144	146	148	150	152	110
115	129	131	133	135	137	139	141	143	145	146	148	115
120	126	128	130	132	134	136	138	140	141	143	145	120
125	124	125	127	129	131	133	135	137	139	141	142	125
130	121	123	125	127	129	131	132	134	136	138	140	130
135	119	121	123	125	126	128	130	132	134	136	138	135
140	117	119	121	123	124	126	128	130	132	134	136	140
145	115	117	119	121	123	124	126	128	130	132	134	145
150	114	115	117	119	121	123	125	127	128	130	132	150
155	112	114	116	118	120	121	123	125	127	129	131	155
160	111	113	114	116	118	120	122	124	126	127	129	160
165	110	111	113	115	117	119	121	122	124	126	128	165
170	108	110	112	114	116	118	120	121	123	125	127	170
175	107	109	111	113	115	117	118	120	122	124	126	175
180	107	108	110	112	114	116	118	119	121	123	125	180
185	106	107	109	111	113	115	117	119	120	122	124	185
190	105	107	108	110	112	114	116	118	120	121	123	190
195	104	106	108	110	111	113	115	117	119	121	123	195
200	103	105	107	109	111	113	114	116	118	120	122	200
250	95	97	99	101	103	105	107	109	111	113	114	250
300	81	83	85	87	89	90	92	94	96	98	99	300
350	59	60	61	63	64	66	67	68	70	71	73	350

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_160	_162	_164	_166	_168	_170	_172	_174	_176	_178	_180	BREAST HEIGHT AGE
60												60
61												61
62												62
63												63
64												64
65	207											65
66	205											66
67	203	206										67
68	201	204	206	208								68
69	200	202	204	207	209							69
70	198	200	202	205	207	209						70
72	195	197	199	201	204	206	208	210				72
74	191	194	196	198	200	202	205	207	209	211		74
76	188	190	193	195	197	199	201	204	206	208	210	76
78	185	187	190	192	194	196	198	201	203	205	207	78
80	182	185	187	189	191	193	195	198	200	202	204	80
82	180	182	184	186	188	190	193	195	197	199	201	82
84	177	179	181	184	186	188	190	192	194	196	198	84
86	175	177	179	181	183	185	187	189	192	194	196	86
88	172	174	176	179	181	183	185	187	189	191	193	88
90	170	172	174	176	178	180	182	185	187	189	191	90
92	168	170	172	174	176	178	180	182	184	186	188	92
94	166	168	170	172	174	176	178	180	182	184	186	94
96	164	166	168	170	172	174	176	178	180	182	184	96
98	162	164	166	168	170	172	174	176	178	180	182	98
100	160	162	164	166	168	170	172	174	176	178	180	100
105	156	158	160	162	164	166	168	170	171	173	175	105
110	152	154	156	158	160	162	164	165	167	169	171	110
115	148	150	152	154	156	158	160	162	164	166	168	115
120	145	147	149	151	153	155	157	159	161	162	164	120
125	142	144	146	148	150	152	154	156	158	159	161	125
130	140	142	144	146	147	149	151	153	155	157	159	130
135	138	139	141	143	145	147	149	151	153	154	156	135
140	136	137	139	141	143	145	147	149	150	152	154	140
145	134	136	137	139	141	143	145	147	149	150	152	145
150	132	134	136	138	139	141	143	145	147	149	151	150
155	131	132	134	136	138	140	142	144	145	147	149	155
160	129	131	133	135	137	138	140	142	144	146	148	160
165	128	130	132	134	135	137	139	141	143	145	147	165
170	127	129	131	132	134	136	138	140	142	144	146	170
175	126	128	130	131	133	135	137	139	141	143	145	175
180	125	127	129	131	132	134	136	138	140	142	144	180
185	124	126	128	130	132	134	135	137	139	141	143	185
190	123	125	127	129	131	133	135	137	138	140	142	190
195	123	125	126	128	130	132	134	136	138	140	142	195
200	122	124	126	128	130	131	133	135	137	139	141	200
250	114	116	118	120	122	124	126	128	130	132	134	250
300	99	101	103	105	107	109	111	112	114	116	118	300
350	73	74	76	77	79	80	82	83	85	86	88	350
400	41	42	43	44	45	45	46	47	48	49	50	400

Table 3—Silver fir site index, in feet, by age at breast height and total tree height[a] (continued)

					H E I G H T						
BREAST HEIGHT AGE	_180	_182	_184	_186	_188	_190	_192	_194	_196	_198	_200	BREAST HEIGHT AGE
80	204	206	208	211								80
82	201	203	205	208	210							82
84	198	201	203	205	207	209	211					84
86	196	198	200	202	204	206	208	210	213			86
88	193	195	197	199	202	204	206	208	210	212		88
90	191	193	195	197	199	201	203	205	207	209	211	90
92	188	190	193	195	197	199	201	203	205	207	209	92
94	186	188	190	192	194	196	198	200	202	205	207	94
96	184	186	188	190	192	194	196	198	200	202	204	96
98	182	184	186	188	190	192	194	196	198	200	202	98
100	180	182	184	186	188	190	192	194	196	198	200	100
105	175	177	179	181	183	185	187	189	191	193	195	105
110	171	173	175	177	179	181	183	185	187	189	191	110
115	168	170	171	173	175	177	179	181	183	185	187	115
120	164	166	168	170	172	174	176	178	180	182	183	120
125	161	163	165	167	169	171	173	175	177	178	180	125
130	159	161	162	164	166	168	170	172	174	176	178	130
135	156	158	160	162	164	166	168	170	171	173	175	135
140	154	156	158	160	162	164	165	167	169	171	173	140
145	152	154	156	158	160	162	164	165	167	169	171	145
150	151	153	154	156	158	160	162	164	166	168	169	150
155	149	151	153	155	157	158	160	162	164	166	168	155
160	148	150	152	153	155	157	159	161	163	165	167	160
165	147	148	150	152	154	156	158	160	162	164	165	165
170	146	147	149	151	153	155	157	159	161	163	164	170
175	145	146	148	150	152	154	156	158	160	162	164	175
180	144	146	148	149	151	153	155	157	159	161	163	180
185	143	145	147	149	151	153	154	156	158	160	162	185
190	142	144	146	148	150	152	154	156	158	160	162	190
195	142	144	145	147	149	151	153	155	157	159	161	195
200	141	143	145	147	149	151	153	155	157	159	160	200
250	134	136	138	140	142	144	146	148	150	152	155	250
300	118	120	122	124	126	128	130	132	134	136	138	300
350	88	89	91	92	94	96	97	99	100	102	103	350
400	50	51	52	53	54	55	56	57	58	59	60	400

[a] Developed from equation 8.

GPO 691-133/82089

Hoyer, Gerald E.; Herman, Francis R. 1989. Height-age and site index curves for Pacific silver fir in the Pacific Northwest. Res. Pap. PNW-RP-418. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p.

Forty felled dominant and codominant Pacific silver fir trees (*Abies amabilis* Dougl. ex Forbes) from 39 locations provided the basis for height-age and site index curves. Trees were from upper slope forests of the Cascade Range in Oregon and Washington. Trees ranged in age from 100 to 300 years and were identified by their height-growth trend as free growing throughout their lives. Twenty additional dominant trees with height growth retarded when they were young were excluded from the site index and height-growth analyses. The early rate of diameter growth of these 20 trees was used to develop a general guideline identifying nonfree-growing dominant trees. Equations and height-age curves are presented. A multiple regression equation was developed to express site index (height at age 100) as a function of total tree height and age at breast height.

Equations were developed to estimate the number of years free-growing trees need to reach breast height for the range of site index values. Conversion equations are provided to estimate height at age 50 for curves representing index heights at age 100. The results give forest managers working tools for use in managing silver fir.

Keywords: Site index, Pacific silver fir, *Abies amabilis*, height growth, dominant, stem analysis, Pacific Northwest.

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